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Psychological Monographs: General and Applied

The Tendency to See Objects As Equidistant and Its Inverse Relation to Lateral Separation[1]

Walter C. Gogel

Army Medical Research Laboratory[2]

Introduction

When distant objects are viewed without optical devices, or when objects are viewed through a device which uses only one eye, binocular disparity (stereopsis) becomes weak or inoperative in determining distance perceptions. If, in addition, the objects appear in a relatively homogeneous field of view, such as an expanse of sky or snow, many of the perspective and overlay cues of distance perception are eliminated. It is of some importance to determine the errors which would occur in the perception of the relative distance of objects under such restricted visual conditions. Even in a situation in which the distance aspects are generally well structured, there may be some objects which have few indicators to relate their apparent distance to that of other objects.

Consider the case in which there are *no* cues present to determine the apparent relative distances of objects. Suppose that under these conditions objects are physically located at different distances from an observer. Where will the objects be seen in depth relative to each other? One possible answer would be that the objects would appear indefinitely located in relative distance. This answer assumes that there is no tendency to see the objects in any particular distance relation when the distance cues are removed. If this answer is correct, it might be expected that, in a situation in which the cues to the relative distance of objects were *severely limited,* the perceived relative distance of the objects would be in agreement with whatever distance cues remained; i.e., the observer would correctly use whatever cues were available in structuring the apparent depth aspects of the visual field. Another answer would be that, in the complete absence of distance cues between objects, all objects would appear to be at the same distance from the observer. If this second answer is correct, a different result would be expected in the situation in which the distance cues between objects were very limited. The tendency to see the objects as equidistant would be opposed to the weak distance cues, with the result that the physically nonequidistant objects would appear to have less depth difference than is actually the case. In the continuum from a perceptually well-defined depth situation to one of very limited cues, it would be expected, if the second answer is correct,

[1] The author wishes to thank John P. Tammaro and Kay Inaba for their help in collecting and analyzing the data.

[2] The opinions or conclusions contained in the present report are those of the author. They are not to be construed as reflecting the views or endorsement of the Department of the Army.

that the tendency to see objects as equidistant would become increasingly important.

There is some evidence that the second is the more accurate answer. Judd (4) has reported that a series of white threads presented against a black background and located at different distances from an observer seemed to be at the same distances as each other when viewed monocularly; whereas, when viewed binocularly, their differences in distance were clearly perceived. In discussing the apparent depth between double images and a binocularly fixated object, Judd states, "And we may assert it as a general principle that in monocular vision objects tend toward a single plane, the plane determined by binocular factors." (4, p. 293.)

In the present study monocular and binocular objects were viewed simultaneously. It is assumed that, under the conditions of this study, stereopsis was effectively absent between a monocular and any of the binocular objects.[3] This situation, in the absence of other depth cues, was used to investigate the question of where two physically nonequidistant objects would appear in distance when cues to their relative distance are weak or absent. From the observations of Judd, it might be expected that a monocular object would tend to appear at the same distance from an observer as a binocular object when there are no other binocular objects in the field of view and when monocular indicators of the relative depth between the two objects are weak or absent. This was studied quantitatively in the first experiment of the present study.

[3] That this is not true under all conditions is illustrated by the Wheatstone-Panum limiting case (5, p. 181-182).

What would the perception be, however, if more than one binocular object were present, with the several binocular objects located at different distances from the observer? Where, in depth, would the monocular object appear under these conditions? The depth between the binocularly viewed objects would be fairly accurately perceived because of the binocular disparity cues. But the monocular object can be arranged to present few or no indications of its relative depth position. This is the type of situation in which the apparent relative distances of some, but not all, of the objects are well defined. This was investigated in the second experiment of this study.

In the third and fourth experiments of this study, size cues were introduced between the monocular object and one or all of the binocular objects. The fourth experiment also was designed to "explain" the results from an experiment discussed in a previous study (3), in which it was found that the effectiveness of the size cue in determining the apparent depth between physically equidistant playing cards, one monocular and one binocular, increased as the lateral separation of the playing cards was increased.

General Method and Apparatus

A method of determining the apparent depth between the monocular and binocular object or objects was required. The method used in three out of four of the present experiments was that described previously (3) in which a small binocular disc was adjusted to apparent distance equality with each of several objects in the field of view. The subject adjusted this disc in its distance from himself but he did not adjust the direction (line of sight) of the disc from himself. This direction was set by the experi-

menter so that the line of sight to the disc was always close to the direction (line of sight) of one of the binocular objects. Consistent with this method, this line-of-sight position of the disc was always closest to that of the same binocular object, regardless of the object to which the disc was to be adjusted in distance. Under these conditions, the difference between the distance adjustment of the disc to apparent equidistance with each of the several objects was taken as a measure of the apparent depth between these objects. It is as though the stereopsis between the binocular disc and its closest line-of-sight binocular object was used in adjusting the disc to apparent equidistance with any other object in the field of view, regardless of whether these other objects were monocularly or binocularly viewed. The experimental justification for this method of measuring apparent distance is contained in a previous report (2).

The disc used in this study was stereoscopically generated rather than being an actual object in the field of view. The particular stereoscopic instrument used to generate the disc has been described by Alluisi and Harker (1). It is the same instrument which was employed in the previous study (3). This instrument consisted of two optical systems, one before each eye of the subject. The right and left optical system independently generated a source of parallel light which was projected as a disc image on the right and left retina, respectively. The right optical system could be rotated by turning an adjustment knob. This changed in continuous amounts the direction at which the parallel light entered the right eye of the subject. The left optical system could not be rotated. Each optical system contained a reflecting-transmitting surface which was positioned so that both the disc image and actual objects in the field of view could be simultaneously visible. The subject looked through a pair of restrictive apertures and binocularly fused the retinal disc images. This resulted in the disc appearing to be located in distance with respect to an actual object. By turning the adjustment knob, the subject could make the disc appear to move in distance with respect to the actual object, and the disc could be adjusted to apparent equidistance with this object. From the interpupillary distance of the subject and the calibration constant of the instrument, the distance position of the disc in centimeters could be calculated for any position at which the subject adjusted the disc. For the purposes of this study, the disc can be regarded as essentially a real object which actually moved toward or away from the subject, depending upon the direction in which the subject turned the adjustment knob. The disc was always viewed binocularly. It was orange in color and subtended 15′ of visual angle.

It usually occurred that one of the objects which was physically located in front of the subject was to be seen monocularly. When this was required, a small, black, opaque screen was introduced between the object and one eye of the subject. The object was visible, however, to the other eye of the subject. The room was dark except for the objects used in the experiment, and the screen was not visible. This screen was carefully placed so that, when it was positioned to make one of the objects monocular, it did not interfere with the binocular view of the other object or objects.

The subjects for these experiments were drawn from a group of approximately 24 men, who were experienced in using the stereoscopic instrument.

Experiment I

Display

Schematic top-view drawings of the situations presented to the subjects are shown in Fig. 1. Object S was a 4.5-cm. white square. Object R was a white rectangle, 2.5 cm. wide and 8.0 cm. high. The centers of the square and rectangle were the same height from the floor. The square was always placed so that its right edge was 1° 53′ of visual angle to the left of the left edge of the rectangle. The square was always viewed binocularly. The rectangle was seen either binocularly or with only the left eye of the subject. The rectangle was always located 303 cm. from the subject. The square was either 250 cm. from the subject (Part A of Fig. 1), or 340 cm. from the subject (Part B of Fig. 1). This resulted in a total of four situations. They were as follows: With the square observed binocularly and the rectangle observed monocularly, the square was (*a*) physically closer to the subject than the rectangle, or (*b*) physically farther from the subject than the rectangle. With both the square and rectangle observed binocularly, the square was (*c*) physically closer to the subject than the rectangle, or (*d*) physically farther from the subject than the rectangle.

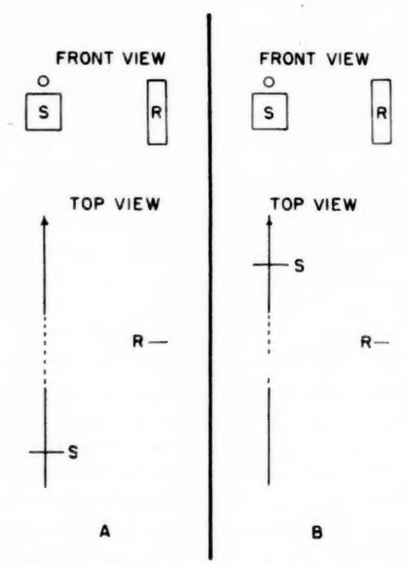

Fig. 1. Schematic front and top-view drawings of the situations used to investigate the apparent depth position of a monocular or binocular rectangle (R) as a function of the depth position of a binocular square (S).

Part A of Fig. 1 illustrates Situations *a* and *c*, and Part B of Fig. 1 illustrates Situations *b* and *d*. It will be observed that the only difference between Parts A and B of Fig. 1 was that the square was moved from a position in front of the rectangle to a position behind the rectangle. With Situation *a* and *b*, stereopsis was effectively absent between the square and rectangle, while with Situations *c* and *d*, the stereopsis cue was present between these two objects. The main interest of the experiment is with the situations in which the rectangle was viewed monocularly (Situations *a* and *b*). The purpose of Situations *c* and *d* is merely to demonstrate that the depth difference between the square and rectangle was readily perceived when the stereopsis cue occurred between the square and rectangle.

The long, arrowed lines in the top views of Fig. 1 approximate the apparent path of depth movement of the binocularly viewed disc in the depth vicinity of the square and rectangle when the subject turned the stereoscopic adjustment knob. If the position of the subject in the top-view drawings were shown in Fig. 1, it would be indicated below the top-view drawings. For all points on the long, arrowed lines, the line-of-sight position of the disc was always closer to the line-of-sight position of the square than

to the line-of-sight position of the rectangle. As indicated by the circle (representing the disc) in the front views of Fig. 1, the line-of-sight position of the disc was always above the square (by 10′ of visual angle). The same line-of-sight position of the disc was maintained regardless of whether the disc was adjusted to apparent depth equality with the square or with the rectangle.

Procedure

The experimenter adjusted the line-of-sight position of the disc so that this position was 10′ of visual angle above the square (see Fig. 1). This line-of-sight position was unchanged throughout the experiment. It was not modified by the subject, whose task was to adjust the stereoscopic instrument knob until the binocular disc appeared to be at the same distance from himself as either the square or rectangle. The difference between the average adjustment of the disc to apparent distance equality with the square and with the rectangle is taken as a measure of the apparent depth between the square and rectangle (3). For any presentation of the square and rectangle, 16 adjustments of the disc to the same apparent distance as one of these objects was followed by 16 adjustments to apparent equidistance with the other object. A bracketing technique was used. In each trial the subject adjusted the disc to appear alternately farther and nearer than the square (or rectangle), with the final approach to the same apparent depth position as the square (or rectangle) occurring with the disc appearing to move toward or away from the subject, according to the instructions. With half the subjects, the final approach to apparent depth equality in the first eight of these depth adjustments was made with the disc moving toward the subject, and in the next eight adjustments with the disc moving away from him. With the remaining subjects, the order was reversed. Eight subjects were used. Each of these adjusted the disc to apparent distance equality with each of the two objects (the square and the rectangle) in each of the four situations, *a*, *b*, *c*, and *d*. The procedure was systematically varied with respect to (*a*) whether the square or rectangle was designated first as the object to which the disc was adjusted to apparent equidistance, (*b*) whether the square was presented first behind or first in front of the rectangle, and (*c*) whether the rectangle was presented first monocularly or first binocularly.

After the 16 adjustments of the disc to the same apparent distance as the rectangle and the square in a particular situation were completed, the subject was asked to estimate the apparent depth difference between the square and rectangle.

The brightness of the square and rectangle was always 2.4 foot-lamberts, as measured with the Macbeth illuminometer. No objects were visible to the subject except the white square, the white rectangle, and the orange disc. The remainder of the room was in darkness.

Results

The summarized results in centimeters from this experiment are shown in Table 1. Each mean in Table 1 is an average of eight scores, one from each subject, in one of the four situations, *a*, *b*, *c*, or *d*. Each score is a mean of 16 depth adjustments of the disc to the same apparent distance as the square or rectangle. The standard deviations of Table 1 were computed from the distributions of eight scores. The statistical significance of the differences between the various means was determined by the

TABLE 1

MEANS AND STANDARD DEVIATIONS IN CENTIMETERS OF THE ADJUSTMENT OF A BINOCULAR DISC TO APPARENT EQUIDISTANCE WITH A MONOCULAR OR BINOCULAR RECTANGLE (R) AND A BINOCULAR SQUARE (S), AS A FUNCTION OF THE DEPTH POSITION OF THE SQUARE

Distance adjustment of binocular disc with respect to:	R Monocular				R Binocular			
	S in Front of R (Situation *a*)		S Behind R (Situation *b*)		S in Front of R (Situation *c*)		S Behind R (Situation *d*)	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
S	254	4.7	342	6.1	254	4.1	343	6.1
R	257	11.7	337	11.4	302	8.8	310	8.6

t test. In calculating the *t* values (in this and the following experiments), a distribution of difference scores was formed from the distributions whose mean difference was to be tested for significance.

Consider the results in the left half of Table 1, obtained from the situations in which the rectangle (R) was viewed monocularly. When the binocular square (S) was located at a distance of 250 cm. from the subject and the rectangle at a distance of 303 cm. (Situation *a*), the average distance adjustment of the binocular disc with respect to the square was 254 cm., and with respect to the rectangle 257 cm. This difference of 3 cm. was not significant at the .10 level of confidence ($t = .7$). This suggests that there was little or no difference in apparent depth between the square and rectangle. Also, when the binocular square was located at 340 cm., with the physical position of the monocular rectangle still at 303 cm. (Situation *b*), the average apparent depth between the rectangle and square was 5 cm. (342 cm. minus 337 cm.). This difference also was not significant at the .10 level of confidence ($t = 1.4$). From these results it seems that the monocular rectangle appeared to be located near or at the distance position of the binocular square for each of the two distance positions of the square. If there was a tendency for the monocular rectangle to appear at the distance of the binocular square, the mean adjustment of the disc to apparent equidistance with the rectangle should differ in Situations *a* and *b*, with Situation *b* resulting in the larger centimeter value. The mean adjustment results on the rectangle were 337 cm. and 257 cm. from Situations *b* and *a*, respectively. This difference of 80 cm. is significant beyond the .001 level of confidence ($t = 11.6$). These results support the conclusion that there is a tendency to see a monocular object at the same apparent distance as a binocular object.

The right half of Table 1 refers to Situations *c* and *d*, in which both the square and rectangle were observed binocularly. It will be seen from these results that the rectangle (R) was clearly (and correctly) perceived as being behind the square (S) in Situation *c*, and in front of the square in Situation *d*. The perceived differences in distance (302 cm. minus 254 cm., and 343 cm. minus 310 cm.) were each significant beyond the .001 level of confidence (*t* being 17.0 and 17.1, respectively). The difference between the mean adjustment results on the rectangle from Situations *d* and *c* was 8 cm. (310 cm. minus 302 cm.). This difference was between the .10 and .05 levels of confidence ($t = 2.0$). One possible interpretation of this 8-cm. difference is that there may have been some tendency to see the rectangle and square

as less different in depth than they actually were. But this tendency was much less effective in the situations in which the rectangle was viewed binocularly than in the situations in which the rectangle was viewed monocularly.

The average verbal report when the square was physically less distant than the rectangle was that the square was 3 in. in front of the rectangle when the rectangle was observed monocularly, and 33 in. in front of the rectangle when the rectangle was observed binocularly. The average verbal report when the square was physically more distant than the rectangle was that the square was 11 in. behind the rectangle when the rectangle was observed monocularly, and 26 in. behind the rectangle when the rectangle was observed binocularly. The direction of these changes in the average verbal report with the change in the method of observing the rectangle (monocular or binocular observation) is in agreement with the direction of the corresponding changes in the mean differences of Table 1.

Discussion

This experiment demonstrates quantitatively that there is a tendency to see a monocular object at the same apparent distance as a binocular object. Actually, there were three, not two, objects in view: the square, the rectangle, and the disc. The only reason for having the disc present was to determine the apparent depth difference between the square and rectangle. Consider the two Situations (*a* and *b*) in which the rectangle was observed monocularly. If the monocular rectangle tended to be seen at the same apparent depth as a binocular object, the presence of the binocular disc might be expected to affect the apparent depth position of the monocular rectangle, whenever the disc was at an apparent depth position which was different from that of the binocular square. But the disc was present and had the same line-of-sight position, both in the situation in which the binocular square was behind the monocular rectangle and in the situation in which the binocular square was in front of the monocular rectangle. Therefore, the difference between the 337- and 257-cm. average depth adjustment of the disc to apparent equidistance with the monocular rectangle can only be attributed to the factor which changed between the two situations, i.e., to the change in the distance position of the binocular square.

EXPERIMENT II

Display

In Experiment I it was quantitatively demonstrated that there is a tendency to see a monocular and binocular object at the same apparent distance. The purpose of Experiment II was to determine whether the strength of this tendency is a function of the lateral line-of-sight separation of the objects. The words *lateral separation,* as they are used here and in the following experiments, refer to relative right or left positions, i.e., to the difference in visual right or left direction between the several objects. Two or more objects can be made to assume any lateral separation with respect to each other, while remaining different in their distances from the subject. In the present experiment, two binocularly viewed white squares (4.5 cm. on a side) and a monocularly viewed white rectangle (2.5 cm. wide and 8.0 cm. high) were used. The monocular object here, as in Experiment I, was of a different shape than the binocular object or objects in order to minimize the use of any size cue between the monocular object and

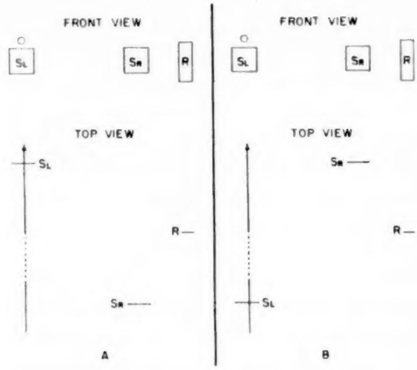

FIG. 2. Schematic front and top-view drawings of the situations used to investigate the apparent depth position of a monocular rectangle (R) as a function of the depth and lateral positions of two binocular squares (S_R and S_L).

a binocular object. Between the binocular squares, however, it was appropriate to have the usual size cue resulting from using similar objects, since it was necessary that the relative distance positions of the squares with respect to each other be clearly perceived.

The two binocular squares and the monocular rectangle were arranged as illustrated by Fig. 2. In Part A of Fig. 2, the square on the left (S_L) was 416 cm. from the subject, and the square on the right (S_R) was 346 cm. from the subject. In Part B of Fig. 2, the distance positions of the two squares were reversed. In this case, the square on the left (S_L) was 346 cm. from the subject and the square on the right (S_R) was 416 cm. from the subject. The monocular rectangle (R) was 381 cm. from the subject in both Part A and Part B of Fig. 2, i.e., physically, the monocular rectangle was always midway in depth between the two binocular squares. While the depth positions of the two squares were reversed in the situations represented by the two parts of Fig. 2, the lateral line-of-sight positions of the squares remained unchanged. In both Part A and Part B of Fig. 2, S_L was 3° 49′ of visual angle to the left of the monocular rectangle (R), while S_R was only 46′ to the left of R. The rectangle was seen always with only the left eye, while the two squares and the disc were always seen with both eyes, i.e., the stereopsis cue occurred between the two squares and between the disc and each square, but was effectively absent between the rectangle and either of the squares or the disc.

The angle formed between the lines-of-sight to R and S_R was considerably less than that between R and S_L. The rectangle (R) was laterally closer to S_R than to S_L. If R, which was physically midway in depth between S_R and S_L, appeared to be located in depth closer to S_R than to S_L, this would be evidence that the strength of the tendency to see a monocular object as equidistant with a binocular object is inversely related to lateral directional separation.

The long, arrowed lines in the top views of Fig. 2 approximate the apparent path of depth movement of the disc in the depth vicinity of the squares and rectangle when the subject turned the adjustment knob. The disc was always seen with both eyes. The line-of-sight position of the disc was always 10′ of visual angle directly above the left square, regardless of where the disc appeared in depth. This position of the disc is indicated by the circle in the front views of Fig. 2. The disc retained this same line-of-sight orientation, regardless of the object to which it was adjusted in apparent depth.

The brightness of the two white squares and the white rectangle was always 2.4 foot-lamberts, as measured with a Macbeth Illuminometer. No objects

were visible in the field of view except the two squares, the rectangle, and the disc.

Procedure

Twelve subjects were used. The task of the subject was to adjust the disc in depth until it appeared to be at the same distance as one of the objects in the field of view. Each of the two squares and the rectangle, in turn, was specified as the object to which the disc was to be adjusted in depth. Each subject was presented with the situation represented by both A and B of Fig. 2. Sixteen successive adjustments of the disc to each object were made by each subject. As in Experiment I, the bracketing technique was used, with the final distance adjustment of the disc systematically varied with respect to whether the disc moved toward or away from the subject. The procedure was systematically varied between subjects with respect to the order of designating each square and the rectangle as the object to which the disc was adjusted in depth, and with respect to whether the situation first presented to the subject was that represented by Part A or Part B of Fig. 2.

After completing the distance adjustments of the disc in either the situation represented by Part A or Part B of Fig. 2, the subject was asked to estimate the depth position of the rectangle with respect to each of the squares.

Results

The summarized results from Experiment II, in centimeters, are given in Table 2. The columns labeled "Mean," in Table 2, contain averages of 12 scores, one score from each subject, where each score is a mean of 16 adjustments of the disc to the same apparent depth as a square or the rectangle, as indicated by the left column. The standard deviations of Table 2 were computed from the distributions of twelve scores.

TABLE 2

MEANS AND STANDARD DEVIATIONS IN CENTIMETERS OF THE ADJUSTMENT OF A BINOCULAR DISC TO APPARENT EQUIDISTANCE WITH A MONOCULAR RECTANGLE (R) AND TWO BINOCULAR SQUARES (S_L AND S_R), AS A FUNCTION OF THE DEPTH AND LATERAL POSITIONS OF THE SQUARES

Distance adjustment of binocular disc with respect to:	S_L Far (A of Fig. 2)		S_L Near (B of Fig. 2)	
	Mean	*SD*	Mean	*SD*
S_L	414	7.4	344	6.4
R	368	23.9	398	36.8
S_R	350	10.7	415	10.7

The column labeled "S_L Far," in Table 2, refers to the situation represented by Part A of Fig. 2. The average apparent distance difference between the left square (S_L) and the rectangle R, as measured by using the disc, is 46 cm. 414 cm. minus 368 cm.). The average apparent distance difference between the right square (S_R) and the rectangle (R) is 18 cm. (368 cm. minus 350 cm.). This suggests that the monocular rectangle usually appeared to be closer in depth to the square to which it was laterally closer (S_R) than to the square from which it was laterally more displaced (S_L). Subtracting the 18-cm. difference from the 46-cm. difference gives 28 cm., which is significantly different from zero at the .05 level of confidence ($t = 2.2$). The column labeled "S_L Near," in Table 2, refers to the situation represented by Part B of Fig. 2. Here, the average apparent relative depth position of the rectangle, as measured by using the disc, is 54 cm. (398 cm. minus 344 cm.) in back of S_L, and 17 cm. (415 cm. minus 398 cm.) in front of S_R. The 54-cm difference is greater than the 17-cm. difference at the .10 level of confidence ($t = 1.8$).

Therefore, from the results of the situations represented by both Part A and Part B of Fig. 2, there is some evidence that the monocular rectangle appeared to be closer in depth to the square to which it was laterally closer (S_R) than to the square from which it was laterally more displaced (S_L). In one situation the rectangle appeared to be closer to the subject than its physical relative position, and in the other situation farther from the subject than its physical relative position. The physical position of the rectangle was the same in both situations. An over-all test of the change in the average apparent position of the rectangle between the two situations can be made. This difference of 30 cm. (398 cm. minus 368 cm.) is significantly different from zero beyond the .01 level of confidence ($t = 3.7$).

The disc adjustment difference of 18 cm. between R and S_R in the situation represented by Part A of Fig. 2 is significant beyond the .02 level of confidence ($t = 2.8$), but the adjustment difference of 17 cm. between R and S_R in the situation represented by Part B of Fig. 2 is not significant at the .10 level of confidence ($t = 1.7$). The 18-cm. adjustment difference suggests that, although the monocular rectangle tended to appear closer in depth to S_R than to S_L, it did not, on the average, appear at the distance of S_R. While the tendency to see R at the depth of S_L was less strong than the tendency to see R at the depth of S_R, the presence of S_L was sufficient to keep the rectangle from appearing at the distance of S_R.

The average verbal report for the situation represented by Part A of Fig. 2 was that the rectangle was 4 in. behind the right square and 25 inches in front of the left square. The average verbal report for the situation represented by Part B of Fig. 2 was that the rectangle was 2 in. in front of the right square and 34 in. behind the left square. These results are in general agreement with the results obtained from using the disc.

The evidence from this experiment is that, in a situation in which two binocular objects are present, a monocular object will tend to appear closest in depth to that binocular object which has the least lateral visual (line-of-sight) separation from the monocular object. It may be concluded that the strength of the tendency to see a monocular object at the same apparent depth as a binocular object decreases as the lateral visual separation of the two objects is increased. The results of this experiment also suggest that binocular objects, other than the laterally most adjacent object, had some effect upon the perceived distance position of the rectangle.

Discussion

Here, as in Experiment I, the disc constituted an additional binocular object. However, the presence of the disc cannot be used to explain the difference which occurred in the average adjustment of the disc to apparent equidistance with the rectangle between the situations represented by Part A and by Part B of Fig. 2. In both situations, the disc was not only present but had the same line-of-sight orientation with respect to the other objects. Therefore, the difference between the 398-cm. and 368-cm. mean adjustment can be attributed only to the change in the distance positions of the binocular squares. In fact, since the bracketing technique was used and the final approach of the disc to apparent distance equality with a particular object was varied with respect to whether the disc moved toward or away from the subject, it is rather difficult to see how

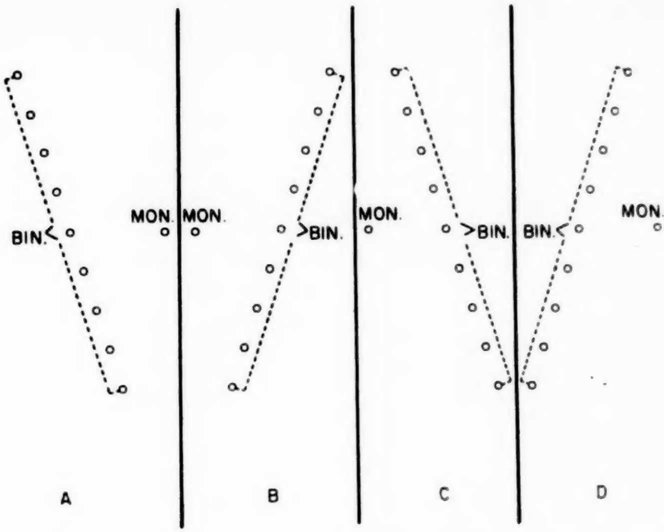

FIG. 3. Schematic top-view drawings of the situations used to investigate the apparent depth position of a monocular cylinder as a function of its lateral position with respect to nine binocular cylinders.

the presence of the disc could have systematically determined the apparent depth between the various objects, either in this experiment or in Experiment I.

The standard deviations of Table 2 with respect to the rectangle are large. It seems that there were some large, individual differences in the perception of the relative depth positions of the monocular rectangle.

Experiment III

Display

In this experiment, nine binocular objects were used. These consisted of a group of upright, internally illuminated white paper cylinders which were placed in a row, with the row located so that it formed a 17.5° angle with an imaginary line drawn from the subject through the middle cylinder. All the cylinders were 4.6 cm. in height and 1.7 cm. in diameter. The separation between adjacent cylinders in the row of cylinders was 15.2 cm.

The row of cylinders receded in distance either from near-right to far-left or from near-left to far-right. The middle cylinder was always 305 cm. from the subject. All the cylinders in the row of nine cylinders were always seen binocularly.

An additional cylinder of the same size was placed to the right or to the left of the row of nine cylinders. This additional cylinder was always seen monocularly. When the monocular cylinder was on the right it was seen with only the left eye, and when the monocular cylinder was on the left it was seen with only the right eye. When this monocular cylinder was on the right or the left, it was laterally separated (in terms of its line of sight) from the most right or most left cylinder in the row of binocular cylinders by 50′ of visual

angle. This monocular cylinder was always placed so as to be the same physical distance from the subject as the middle cylinder in the row of cylinders (305 cm.). The cylinders were internally illuminated to a brightness of 0.3 foot-lamberts. No objects were visible to the subjects except the row of nine cylinders and the monocular cylinder. The stereoscopically generated disc was not used in this experiment.

Four situations resulted. Top-view, schematic representations of these situations are shown in Fig. 3. If the position of the subject were shown in Fig. 3, it would be indicated below the top-view drawings. In the situations represented by Parts A and B of Fig. 3, the binocular cylinder which was closest in distance to the subject was also the binocular cylinder which was laterally closest to the line of sight from the subject to the monocular cylinder. In the situations represented by C and D of Fig. 3, the binocular cylinder which was farthest in distance from the subject was also the binocular cylinder which was laterally closest to the line of sight from the subject to the monocular cylinder. If the inverse relation between lateral separation and the strength of the tendency to see a monocular object at the same distance as a binocular object was effective in these situations, it would be expected that the binocular cylinder which appeared to be at the same depth as the monocular cylinder would be a cylinder which was closer to the subject in Situations A and B than in Situations C and D of Fig. 3.

Procedure

Twenty-four subjects were used. Their task was to judge which of the cylinders in the row of (binocular) cylinders was most nearly at the same depth as the additional (monocular) cylinder. The nearest binocular cylinder to the subject was designated "one," and the farthest binocular cylinder from the subject was designated "nine," with the other binocular cylinders numbered accordingly. In order to be certain that the depth in the row of binocular cylinders was clearly perceived, the subjects were questioned about the orientation of the row of nine cylinders before the required judgment was made. Each subject was presented with each of the four situations, A, B, C, and D. The order in which these situations were presented was varied between subjects so that all possible permutations of A, B, C, and D were used.

Results

The average of the reports from the 24 subjects and the standard deviations of these reports are given in Table 3. The situations, A, B, C, and D, which are shown in the column headings of Table 3, are those represented in Fig. 3. For example, with Situation A of Fig. 3, the average of the reports was that the additional cylinder (the monocular cylinder) was at a depth position midway between the third and fourth cylinder (3.5), counting from the near end of the row of cylinders. In both Situations A and B, the monocular cylinder was, on the average, seen as closer in depth to the front cylinders in the row of cylinders than to the back cylinders, while in

TABLE 3

MEANS AND STANDARD DEVIATIONS OF THE APPARENT DEPTH POSITION OF A MONOCULAR CYLINDER, AS A FUNCTION OF ITS LATERAL POSITION WITH REGARD TO NINE BINOCULAR CYLINDERS*

Measure	Situation A	Situation B	Situation C	Situation D
Mean	3.5	3.4	7.3	7.4
SD	2.3	1.5	1.8	1.6

* For explanation of table, see text.

Situations C and D the reverse was true. The average report from A (3.5) was significantly different from the average report from either C (7.3) or D (7.4) beyond the .001 level of confidence (t = 6.0 and 7.9, respectively). The average report from B (3.4) was significantly different from that from either C or D beyond the .001 level of confidence (t = 7.5 and 8.6, respectively). Also, each mean report differs from 5 (the number of the binocular cylinder whose distance from the subject was physically the same as that of the monocular object) beyond at least the .01 level of confidence (the t values being 3.0, 5.2, 6.2, and 7.0 for A, B, C, and D, respectively). These results clearly indicate that the tendency for a monocular object to be seen more in the depth direction of those binocular objects which were less laterally displaced from it was effective in these situations.

Discussion

Since all the cylinders were physically identical, size cues were available in the situations used in this experiment. It will be noted that the retinal size of the monocular cylinder was the same as that of the fifth cylinder. The results that were obtained occurred in spite of this size cue. It seems that the tendency for a monocular object to be seen at the depth of a binocular object should not be regarded as a factor which is important only when no other factors are available to determine the perception. It may, therefore, be of consequence in a variety of situations. It is suggested that this tendency is present to some extent in all situations in which more than one object is visible. But if other factors that localize a particular object in depth are strong, the effectiveness of this tendency on that particular object will be restricted.

This tendency and its relation to lateral separation should not be considered as operating only between a monocular and binocular object. There appears to be little reason why it should not also apply to the apparent depth between several monocular objects, or even between several binocular objects if, in this latter case, the binocular cues are sufficiently weak.[4]

The tendency to see objects as equidistant does not always act to eliminate the perception of depth differences. If depth occurs in the visual field through the action of other factors, the tendency to see objects as equidistant with its inverse relation to lateral separation may result in an increase in the apparent depth differences between some of the objects. For example, this factor produced an apparent depth difference in the present experiment between the monocular cylinder and the fifth cylinder in the row of binocular cylinders.

Experiment IV

Display

It was found in a previous study (3) that the apparent depth between two differently sized playing cards which were physically at the same distance from the subjects increased as the lateral separation of the cards was increased. The situation which is of interest here is the case in which one of the two cards was viewed binocularly and the other monocularly. Since stereopsis was effectively absent between the monocular card and the binocular card, the factors to be considered are the size cue and the tendency to see a monocular object at the same

[4] Applications of this tendency to situations of these types are found in Reports No. 148 and 157, Army Medical Research Laboratory, Fort Knox, Kentucky.

distance as a binocular object. In this particular case, these two factors were opposed in their effects, i.e., the size cue should have operated to make the larger card appear closer than the smaller card, while the above tendency should have operated to make the cards appear equidistant. It is possible, therefore, that the increase in the apparent depth between the cards when the lateral separation of the cards increased was due to the inverse relation between lateral separation and the tendency to see a monocular and binocular object as equidistant, rather than to any change in the strength of the size cue to relative depth.

To investigate this, a binocular normal-sized playing card and a monocular double-sized playing card were used with a 22.9-cm. lateral separation between their inner edges. The double-sized card was on the right and the normal-sized card was on the left. Each of these two cards was located at a distance of 303 cm. from the subjects. This was identical with one of the situations used in the previous study (3), except that a diamond-shaped figure (11.9 cm. by 4.8 cm.) was sometimes present. When the diamond-shaped figure was used, it was placed 55 cm. behind the two physically equidistant playing cards, with the right corner of the diamond laterally displaced to the left of the double-sized playing card by 51 minutes of visual angle, and its left corner laterally displayed to the right of the normal-sized playing card by 2° 23′ of visual angle. Schematic representations of the situations used are shown in Fig. 4. Part *a* of Fig. 4 represents the situation in which the diamond was absent, and Part *b* of Fig. 4 the situation in which the diamond was present. The two situations are identical in all other respects. In both situations the size difference between the two cards would tend to make the double-sized card (Card B of Fig. 4) appear closer to the subject than the normal-sized card (Card A of Fig. 4). With the diamond present, the binocular disparity cue between the normal-sized card and the diamond should make the diamond appear to be more distant than this card. But there was effectively no stereopsis between the binocular diamond and the monocular double-sized card. Therefore, when the diamond was present, the tendency for the monocular object (the double-sized card) to be seen nearest in distance to the laterally nearer object (the diamond) would tend to make the double-sized card appear behind the normal-sized card. It would be expected, therefore, that when the diamond was present, the double-sized card should appear less far in front of the normal-sized card than in the situation in which the diamond-shaped object was absent.

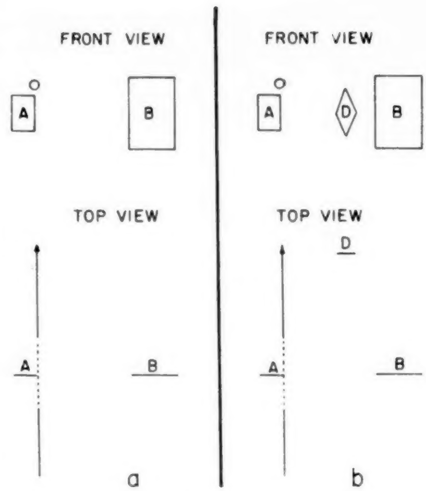

FIG. 4. Schematic front and top-view drawings of the situations used to investigate the effect of the presence of a diamond-shaped figure (D) upon the apparent depth between two differently sized playing cards (A and B).

Procedure

As in the first two experiments of this study, the stereoscopically generated disc was used to measure apparent depth, in this case, between the two playing cards. As indicated in Fig. 4, the line-of-sight position of the disc was always such that the line of sight to the disc was above (10′ of visual angle) the line of sight to the normal-sized playing card. Eight subjects were used. The subjects were asked to adjust the disc to apparent depth equality with each of the playing cards, both when the diamond-shaped object was present and when it was absent. The bracketing technique was used, with the final distance adjustment of the disc systematically varied with respect to whether the disc moved toward or away from the subject. The procedure was systematically varied between subjects with respect to (*a*) whether the situation represented by Part *a* or by Part *b* of Fig. 4 was presented first, and (*b*) whether the left or right card was designated first as the object to which the disc was to be adjusted in distance. No objects were visible except the disc, the two playing cards, and the diamond-shaped figure when it was present.

Results

The summarized results from this experiment are shown in Table 4. Each mean in the table is an average of eight scores, one from each subject, where each score is the mean of 16 adjustments of the disc to a particular playing card. The standard deviations of Table 4 were computed from the distributions of eight scores.

TABLE 4

MEANS AND STANDARD DEVIATIONS IN CENTIMETERS OF THE ADJUSTMENT OF A BINOCULAR DISC TO APPARENT EQUIDISTANCE WITH TWO DIFFERENTLY SIZED PLAYING CARDS DEPENDING UPON WHETHER A DIAMOND-SHAPED FIGURE (D) IS PRESENT OR ABSENT

Distance adjustment of binocular disc with respect to:	D Absent		D Present	
	Mean	*SD*	Mean	*SD*
Normal Card	305	6.4	304	5.7
Large Card	282	17.2	312	30.3

It will be seen from the mean results of Table 4 that when the diamond-shaped figure was absent, the average apparent depth between the two playing cards, as measured by using the disc, was 23 cm. (305 cm. minus 282 cm.), with the double-sized card appearing in *front* of the normal-sized card. But when the diamond was present, the average apparent depth between the two playing cards, as measured by using the disc, was 8 cm. (312 cm. minus 304 cm.), with the double-sized card slightly in *back* of the normal-sized card. The difference (31 cm.) between these two pairs of results is significant beyond the .01 level of confidence ($t = 3.9$). The average verbal report was that the right card was 11 in. in front of the left card when the diamond was absent, and 1 in. in front of the left card when the diamond-shaped figure was present. It seems that the inverse relation between lateral separation and the strength of the tendency to see a monocular object at the apparent distance of a binocular object is capable of significantly modifying the apparent depth difference produced by relatively strong size cues.

Discussion

It appears that the increase in the effectiveness of the size cue to relative depth with increased lateral separation found in the previous study (3), when one of the playing cards was monocularly and the other binocularly viewed, can be explained by the inverse relation be-

tween lateral separation and the strength of the tendency to see objects as equidistant. Increasing the lateral separation of the playing cards reduced the restrictive influence of the tendency to see the playing cards as equidistant and, as a result, the size cue between the cards had an increasingly important role in determining the relative distance perception. Similarly, it also might be expected that the effectiveness of other monocular cues of relative distance, such as brightness differences between objects, would be a function of the lateral separation of these objects.

General Discussion

In a situation in which no cues to the relative depth location of objects are present, the objects probably will tend to be seen as equidistant, regardless of their lateral positions. This is expected to occur, even though the evidence is that the strength of the tendency to see objects as equidistant decreases as the lateral line-of-sight separation of the objects is increased. If there are no opposing factors, even the weak equidistance tendencies resulting from large lateral separations will probably be effective.

In the second experiment the binocular disparity cue was present to produce the apparent depth between the two squares. The monocular rectangle had no strong relative distance cues to determine its depth position with respect to the squares. To the extent that the monocular rectangle appeared to be closer in depth to the laterally closer square, the tendency for the rectangle to appear at the depth of the laterally closer square was stronger than the tendency for it to appear at the depth of the other square. In the third experiment, binocular disparity cues were present to produce the apparent depth between the binocular cylinders. The size cue resulting from similarity of shape was present between the monocular cylinder and the binocular cylinders. In spite of this, the monocular cylinder appeared to be displaced from its physical relative depth position toward the depth position of the laterally closer binocular cylinders. In the fourth experiment, binocular disparity cues were present to produce apparent depth between the diamond-shaped figure and the left (binocular) playing card. Despite fairly strong size cues between the binocular and monocular playing cards, the relative depth position of the monocular playing card differed, depending upon whether or not the diamond-shaped figure was present. These last three experiments of the study represent the type of situation in which the apparent distance aspects of parts of the field of view are fairly well determined. It is found that the apparent depth position of an additional object with less strong distance cues can be influenced by the inverse relation between lateral line-of-sight separation and the tendency to see objects as equidistant.

Summary and Conclusions

It was demonstrated quantitatively that there is a tendency for a monocular object to be seen at the same apparent distance as a binocular object. More generally stated, the conclusion would be that two objects tend to be seen at the same apparent distance. The presence of strong binocular cues, however, can severely restrict or eliminate the effectiveness of this factor. Experimental results indicate that the strength of the tendency for objects to appear equidistant decreases as the lateral line-of-sight separation of the objects is increased. This was demonstrated in sev-

eral visual situations, and the tendency seems to be sufficiently strong to modify relative distance perceptions in situations involving size cues. These results were used to "explain" the increase in the effectiveness of size cues with increased lateral separation, which was found in that part of a previous study (3) in which stereopsis was effectively absent between the two similar but differently sized objects.

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